# Chapter 20
# Reservoir Sedimentation Surveys

## 20-1. Introduction and Background

The Corps maintains some 383 flood control reservoirs such as the project shown in Figure 20-1. These reservoirs are primarily used for flood control water storage. Multipurpose reservoirs include some 75 hydropower projects operated by the Corps--generating nearly 25% of the nation's hydroelectric power output. Other secondary uses of these reservoirs include recreation and water supply. Reservoirs are impounded by either concrete or earth-fill dams. A variety of outlet works and spillways are used to regulate, control, or release outflows from the reservoirs. Reservoir storage capacity impacts hydroelectric power generation and flood control operation. Useful storage is the volume of water between the minimum pool (e.g., outlet invert elevation) and normal pool (e.g., spillway crest elevation) levels. Storage capacities are affected by sedimentation build up over time--typically below the minimum pool elevation. Reservoir sedimentation surveys are performed to monitor periodic build up of sediment in the reservoir, which allow computation of reductions in reservoir capacities. Other purposes may include base data for recreational navigation maps or charts in support of Natural Resources office activities--e.g., topographic/bathymetric maps depicting fishing or camping areas. Reference should be made to EM 1110-2-4000 (Sedimentation Investigations for Rivers and Reservoirs) for planning, conducting, and modeling reservoir sedimentation investigations.

**Figure 20-1. Reservoir behind Mark Twain Dam (St. Louis District)**

## 20-2. Survey Methodology

Reservoir sedimentation surveys require a combination of hydrographic and topographic methods. Hydrographic surveys are performed to determine the underwater topography. Topographic and photogrammetric methods are performed to map the areas above the pool in which the hydrographic surveys were performed. The surveys are merged into a digital terrain database from which quantity take-offs are made for reservoir capacities.

*a. Survey boats.* Hydrographic surveys are usually performed with small, trailerable boats, using standard automated hydrographic data collection systems. Many reservoirs have boat ramps for recreational purposes, so larger, trailerable boats can be easily launched. If there are no launching facilities, a small, carryable, 12- to 16-ft open skiff may have to be used--provided reservoir conditions are calm and protected. Jet ski boats have also been used to survey inaccessible reservoirs. Their use is expected to expand in the future.

*b. Horizontal positioning.* The most efficient positioning method is meter-level, code phase DGPS--using USCG radiobeacons or private provider networks. Alternately, electronic total stations may be used for small reservoirs or impoundment basins; however, this may require locating or establishing additional horizontal control points around the basin, adding considerable time and cost to the survey. Total station positioning may be needed near dams, power plants, or outlook structures if satellite signals are obscured or interfered with. Positional accuracy is not critical for reservoir sedimentation surveys--the 5 meter RMS level recommended in Table 3-1 is more than adequate. This is easily achievable with current DGPS methods. Positioning procedures and calibration checks should conform to the guidance in this manual.

*c. Reference elevations.* Depth measurement accuracy is critical in reservoir sedimentation surveys. Depths are measured relative to either NGVD 29 or NAVD 88 datums. The master gage or staff elevation reference used for the project should be used as a reference--usually located near the outlet works or dam. The elevation of the gage/staff should be checked by connection to existing benchmarks. For long reservoirs, a slope gradient may exist; requiring additional gages be set in the upper reaches. Gages must be continuously monitored if there are short-term fluctuations in the pool; otherwise, twice-daily readings may be adequate. Bar checks are critical to ensures no systematic errors are present--especially on small boats. Sound velocity probes are needed to measure and correct for velocity changes in deeper reservoirs, i.e., at depths beyond the bar check reach and where changes in water temperature are most likely. Since most velocity probes are designed for 50-75 ft navigation projects, additional cable must be added to reach down to 200-300 ft depths.

*d. Density of coverage.* The topographic relief and size of the reservoir will dictate the coverage requirements. Single beam echo sounders are used; however, a multibeam system might be employed if full coverage detail is required for scour studies near the dam or outlet works. Single beam survey lines are typically run bank-to-bank perpendicular to the axis of the reservoir. Since the objective is to compute the volume of an irregularly shaped impoundment basin, there is no rigid requirement for a specific cross-section alignment or spacing. Typically lines are spaced between 200 and 400 ft, with a not-to-exceed spacing specified. If the topography in the reservoir is fairly uniform, then line spacing may be increased. Specifying too tight a line spacing on a large reservoir is uneconomical. The accuracy requirements of the reservoir capacity computation must be fully considered in selecting a line spacing. Since volumes are typically computed by contour intersect methods, the accuracy of the reservoir storage volume is a primary a function of the computed areas for each elevation stage. Thus the digital terrain model (DTM) must have sufficient density to delineate accurate contours from which areas are computed.

(1) Since successive surveys are measuring storage trends, it is only necessary to obtain data at a density consistent with this requirement--e.g., 1% of capacity. Given a percent error in capacity (acre-ft), area (acres), and average depth at spillway elevation, the average accuracy of the 1-ft DTM contours (in ± acres) can be computed. In general, a contour acreage accuracy of ± 1 acre is easily achievable if the survey density is adequate.

(2) Depth accuracy must be absolutely free of any systematic biases. A bias of say (+) 0.3 ft over a 1,000 acre reservoir (i.e., 300 acre-ft) would represent a significant error (3%) even if the storage is only 10,000 acre-ft. Thus, accurate gage readings, bar checks, and velocity calibrations are critical to preclude against systematic errors in reservoir surveys. Random errors in the depth measurements are not significant as long as there is no bias--e.g., a depth accuracy of +0.0 ft (bias) ± 1.0 ft (random) is acceptable, whereas an accuracy of (-) 0.3 ft ± 0.3 ft is not. Refer to Chapter 4 for further discussion on depth accuracy requirements.

*e. Topographic mapping.* In order to compute the full capacity rating for a reservoir, topography must be obtained up to the normal pool or spillway crest elevation; or higher, to a surcharge elevation that may be specified. Existing maps or as-built drawings of the project may already be available for this data; otherwise, full topographic and/or photogrammetric mapping surveys of these areas will be required. Approximate computations may be made using USGS quad maps; however, their small-scale and poor vertical accuracy will often not provide adequate results.

*f. Area and capacity computations.* A variety of automated techniques are used to compute the storage area-capacities. Usually the hydrographic-topographic DTM is used to generate a TIN model when only sparse cross-section data are available. From this TIN, 1-ft contours are generated and the area (in acres) for each 1-ft contour section computed. The volume (in acre-ft) for each contour segment can be computed by projecting this area over the contour 1-ft interval. More refined prismoidal adjustments may be made. The areas and accumulated storage volumes are tabulated and plotted on a standard area-capacity curve format as illustrated in the following example project. Reservoir storage capacity relative to the watershed area runoff may also be computed and tabulated in acre-ft per inch of runoff.

## 20-3. Application: Hydrographic Surveys and Area Capacity Curves--Baltimore District

The following project illustrates a typical reservoir sedimentation survey for the purpose of updating area capacity curves. The overall project involved sedimentation surveys for seven reservoir projects in Baltimore District. Results for only one of these projects is illustrated herein. This hydrographic surveys on the reservoir were conducted by TVGA, Inc., Elma, NY. Another contractor subsequently completed the topographic mapping portion of the work. Baltimore District then merged the two files to obtain a DTM from which they computed reservoir storage area-capacities. St. Louis District managed the hydrographic and photogrammetric mapping contracts for the Baltimore District.

*a. Task order scope of work.* The following Scope of Work was sent to the contractor as part of a Request for Proposal on the project. This scope succinctly describes the work to be performed and deliverables.

**SCOPE OF WORK**
**TVGA ENGINEERING, SURVEYING, INC**
**ELMA, NY**
**SEVEN LAKES FOR BALTIMORE DISTRICT**
**HYDROGRAPHIC SURVEYS**

**CONTRACT NO. DACW43-96-D-0512**
**TASK (DELIVERY) ORDER NO. XXX**

1. Description of Work:

The Contractor shall perform hydrographic surveys in the Baltimore District at seven lakes to be used to update area capacity curves to reflect the changes in storage volumes as a result of sedimentation. The seven lakes are (1) East Sidney, (2) Whitney Point, (3) Bush Dam, (4) Stillwater, (5) Aylesworth Creek Lake, (6) Jennings Randolph, and (7) Almond Lake. The lakes are located in the vicinity of northern Pennsylvania, West Virginia, and New York.

2. Information Supplied by the Government:

a. Copies of USGS Quadrangle sheet covering the five lakes with pertinent areas outlined.

b. Copies of project maps for each lake.

c. Copies of mapping specifications, for merging hydrographic surveys with the mapping being performed by others.

d. Copy of list detailing specification for individual lake. Sounding range distance interval for the lakes are listed for each lake.

e. Copy of memo from Baltimore District detailing survey requirements to be coordinated with the St. Louis District.

3. Work to be Performed by the Contractor:

The Contractor shall provide equipment, supplies, personnel, and survey boat fully equipped to perform control and standard hydrographic surveys utilizing differential global positioning system technology. Specific work shall include:

a. Take sounding along range lines spaced at 100 ft to 250 ft. intervals, but close enough so each lake bottom can be adequately defined for mapping purposes, for hydrographic surveys on the seven (7) lakes furnished in 2.b above. The surveys must be obtained during periods when each lake is below the summer conservation pool (elevation on list provided in 2.d above. The Contractor is required to maintain close coordination with CELMS-ED-HG (Bob Mesko) or CENAB-EN-GW (Bill Haines) to ensure water conditions are being met for each survey. Calibration for fathometer shall be obtained and submitted for each lake surveyed. The surveys shall meet the requirements for class I hydrographic surveys at stated in EM 110-2-1003, 31 October 1994, "HYDROGRAPHIC SURVEYING".

b. Gage readings shall be recorded twice each day for the nearest upstream and downstream gages where soundings are being taken. Also, if surveying in an area where lake gages may not accurately reflect water surface conditions, levels shall be run to water surface.

c. All surveys shall also be submitted to the St. Louis District in 3D CADD files fully operational on ARC/INFO GIS system. For hydrographic surveys, reference soundings to the National Geodetic Vertical Datum (NGVD).

d. The Contractor shall prepare a bathymetric contour map for each lake showing 1996 conditions, extending from the lowest points in each lake up to the summer conservation pool elevation. The desired contour interval is two (2) feet and the horizontal scale is 1 inch equals 200 ft, unless other scales become required to match the mapping being performed by others. Plots shall be provided for both the soundings data in NGVD and contours.

e. Paper check plots shall be provided to the Government for checking and reviewing of the finished product. The maps shall be prepared on standard engineering size drawings (30" x 42"). The standard Baltimore District title block shall be placed in the lower right corner.

f. Using the hydrographic surveys, compute elevation-area and elevation capacity relationships for each lake from the lowest point in the summer conservation pool elevation. The Contractor shall furnish data in both tabular and graphical format.

g. Visits to each project site shall be pre-coordinated (date, time, purpose) with Mr. William Haines, who will advise the dam operator. Upon arriving at a project site, St. Louis District personnel or their contractors shall check in with the dam operator before beginning work

h. Lakes at the various projects are subject to rapid and frequent changes in water levels, depending upon hydrologic conditions. Field work should be scheduled and accomplished with the understanding that the lake levels may fluctuate daily or even hourly, and there may be times when vessels are prohibited on the lakes.

i. The Contractor shall compare the DGPS positioning system to a minimum of one known survey control point in the vicinity of each lake surveyed.

4. <u>End Results Expected:</u>

a. Listing (coordinates) of any additional horizontal control established. Include field books showing plan view, location, references, and procedures used to establish new points. Field books shall include neat sketches showing bearings, angles, and taped distances to at least three nearby distinct permanent objects.

b. Quality reproducible mylars and five black line copies of the 1996 contour maps and soundings. Electronic data files for bathymetry maps in both contour and elevation form, for use in an ARC/INFO system as described in para. 3.d above. Maps shall be prepared on standard engineering size drawings (30"x42"). The standard Baltimore District title block shall be placed in the lower right corner.

c. Fathometer scrolls showing sounding lines cross-referenced to plan view plots in 4.b. above, complete set of survey notes, 3.5-inch diskettes, and any other medium containing raw survey data. This package is to be accompanied by documentation indicating the data type, the data format, and general instruction for its retrieval.

d. New monuments established in the field as necessary to perform hydrographic survey.

e. Corps of Engineers Form DA 1959 completed with information concerning any new control points which may have been set.

f. Diskettes containing the 3D CADD digital data files of the hydrographic surveys, fully operational on the District ARC/INFO system.

g. Original and five copies of curves and tables for the 1996 elevation-area and 1996 elevation capacity relationships. Electronic data files for curves and tables will also be submitted.

h. Bi-weekly progress reports shall be submitted to the St. Louis District and Baltimore District. This report may be made electronically (e-mail) or via fax. The POC in Baltimore is Mr. J. William Haines, CENAB-EN-GW, Phone (410) 962-6768 and FAX (410) 962-4972.

5. <u>Schedule and Submittal:</u>

The Contractor shall prepare and submit all pertinent data to the Corps of Engineers, ED-HG (Attn: Bob Mesko), 1222 Spruce, St. Louis, MO 63103-2833 by 31 January 1997 for every project except Jennings Randolph Lake. For Jennings Randolph Lake all information and deliverables not later than 1 June 1997 shall be submitted. Close coordination is required with ED-HG (Bob Mesko) to ensure the surveys are being obtained during period of summer conservation pool and before draw down occurs. Incremental submittals of surveys are required for the District to comment on format and content of the data. Scheduled draw downs will occur in the fall at East Sidney Lake and Whitney Point Lake. Field work must be completed at these project not later than 15 November 1996. Jennings Randolph is already being drawn down for the winter season. Refilling normally occurs in the early spring, but remains at full conservation pool for only a few weeks before whitewater, water quality, and water supply releases begin. It is anticipated that the hydrographic survey for this project will be scheduled for late March or early April 1997.

Hydrographic surveys, bathymetric maps, and area/capacity computations may be submitted to the Baltimore District and St. Louis District as projects are completed.

6. <u>Time Extensions:</u>

In the event these schedules are exceeded due to causes beyond the control and without fault or negligence of the contractor, as determined by the Contracting Officer, this delivery order completion date will be extended one (1) calendar day for each day of delay.

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*b. Final survey report for Almond Lake*. Following is the final survey report submitted by the contractor in May of 1997 transmitting the sedimentation survey results for one of the seven reservoirs included under the task order.

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SURVEY REPORT

ALMOND LAKE, NY
CANACADEA CREEK
SUSQUEHANNA RIVER BASIN
HYDROGRAPHIC CONDITION SURVEY

CONTRACT DACW43-96-D-0512 (ST. LOUIS DISTRICT)
TASK (DELIVERY) ORDER NO. 003

TVGA Engineering, Surveying, P.C. was requested by the US Army Engineer District, Saint Louis to provide Professional Hydrographic Surveying Services to the US Army Engineer District, Baltimore under Delivery Order Number 003 of Indefinite Delivery Contract DACW43-96-D-0512. TVGA's general responsibilities related to this project consisted of the following:

1. Conduct a hydrographic condition survey to update area capacity curves that would reflect any changes in the storage volumes as a result of sedimentation. The survey operations were to be conducted at a time when the pool elevation was at/or above the recreation level. The limits of our survey were to extend to all portions of the lake which were navigable with a shallow water survey system.

2. Convey results of the field survey through preparation of deliverables that include but are not limited to: plan view mapping to present hydrographic data obtained by the survey and contours at a 2 ft interval and to provide an updated area/capacity table and curves.

**RECORD RESEARCH AND SURVEY SETUP**

TVGA retrieved 7.5-minute United States Geodetic Survey (USGS) quadrangle maps from in-house records to plan the survey. The contour depicting the recreation pool elevation of 1260' above the National Geodetic Vertical Datum of 1929 9 (NGVD 29) was digitized from the quadrangle maps and subsequently used to pre-plan the location of cross sections to be surveyed. Cross sections were spaced at a 250' maximum interval and generally situated perpendicular to hydraulic flow--[see Figures 20-2 and 20-3]. The digitized cross sections were uploaded into Coastal Oceanographics' HYPACK Software and subsequently used during field operations as a base reference for left/right navigation information on the survey vessel.

**HYDROGRAPHIC CONDITION SURVEY**

The survey was conducted at a time when the top of water elevation was above the recreation pool elevation of 1260'. An automated electronic survey system was used to collect hydrographic survey data. The survey system was mounted on-board a 16' aluminum boat. The survey vessel's hull draft of approximately 0.9' and a propulsion draft of approximately 2.0' permitted safe navigation into 2.5' of water. Horizontal positioning data was supplied by an Omnistar, Inc. Model 6300A Differential Global Positioning System (DGPS). Depth data was provided by an Odom Hydrographic Inc. Model DF 3200 Mark II Echo Sounder equipped with a single 208 kHz / 3 degree transducer. Horizontal positioning data and digital depth data were logged directly onto a Toshiba 4400C laptop computer equipped with Coastal Oceanographics' HYPACK Hydrographic Survey Software. HYPACK Software was utilized to plan the survey, display real time vessel navigation information and review survey data on a daily basis.

The survey was performed in accordance with Class I accuracy specifications as described in the US Army Corps of Engineers Engineering and Design Manual EM 1110-2-1003, dated October 31, 1994 and titled Hydrographic Surveying. A generalization of specifications contained in the above EM manual that were implemented during field survey operations included but were not limited to:

1. A daily check and/or calibration of the echo sounder to verify and/or adjust for draft, squat and sound velocity. The Daily Depth Sounder Calibration Logs are included in Section H of this report.

2. A relative check of the Omnistar positioning system was made on a daily basis. This was accomplished by recovering and subsequently comparing the published geodetic coordinates of a National Geodetic Survey (NGS) survey marker with geodetic coordinates derived by the Omnistar positioning system. Xerographic copies of the field notes documenting the daily comparison are included in Section H of this report.

3. Collecting and reviewing data along cross section check lines (longitudinal sections).

4. Compensation for system latency.

Reasonable care was taken in the preparation and performance of the survey to ensure the best possible results. Copies of daily calibration reports are included Section H of this report. Weather and atmospheric conditions at the time of hydrographic survey did not in our opinion contribute any degradation in the expected survey results.

At the conclusion of the survey, the US Army Engineer District, Baltimore supplied TVGA with a Xerox copy of hourly pool elevation data recorded by an electronic gage located near the dam. As a precaution to loss of this electronic gate data, TVGA periodically interrogated the gage during survey operations and reported the data in a hard bound field book.

**PREPARATION OF PROJECT DELIVERABLES**

The hydrographic survey data was up-loaded onto a office based computer equipped with Coastal Oceanographics' HYPACK Hydrographic Survey software. HYPACK Software was utilized to sort, edit and apply water level corrections to digital cross section data. Digital depth data was compared against analog depth charts to correct (edit) depth spikes or false bottom returns caused by interference in the water column. Cross section data was sorted (thinned) to a 20' interval.

The edited cross section data set was read into a Bentley Systems, Inc. MicroStation 95 Version 5.05 3D CADD format. The cross section data was reviewed and a series of terrain break lines were constructed through the low point of each cross section and around the perimeter of the lake. A Triangulated Irregular Network (TIN.) was developed by Intergraph Inroads Version 5.01 software. Contours at 1' and 2' intervals were derived from the digital TIN generated from field collected hydrographic survey data and digital terrain break lines. (Figure 20-4)

Plan view mapping that shows final elevations from echo soundings and contours at a 2' interval was drafted at a scale of 1"=200'. The mapping was finalized using the aforementioned MicroStation software. The mapping is in compliance with the US Army Corps of Engineers, Engineering and Design Manual EM 1110-1-1807, dated July 30, 1990 and titled Computer-Aided Design and Drafting (CADD) Systems. Copies of this mapping plotted at ½ the original size are included in Section E of this report.

The contours generated at a 1' interval were read into Eagle Point software through a Drawing Interchange Format (.DXF). This software was used to compute areas and storage volumes at a 1' interval. The digital ASCII reports produced by Eagle Point software were read into Microsoft Excel Version 7.0. to finalize the area/capacity table and curves.

A system of checks and balances were performed on data to ensure the data's integrity and completeness. A comparison between new and old area/capacity data revealed some differences. The reasons for these differences can most likely attributed to the dynamic environmental conditions (sediment transfer) inherent to this type project, dissimilarities in methodology and equipment used to conduct the original field survey and the new survey and methodology used to compute the storage capacities.

**POINTS OF CONTACT (Phone 716-655-8842)**

Project Manager: Clinton E. Johnson

Field Work: Aaron C. Kennerly

Processing: Scott E Waite

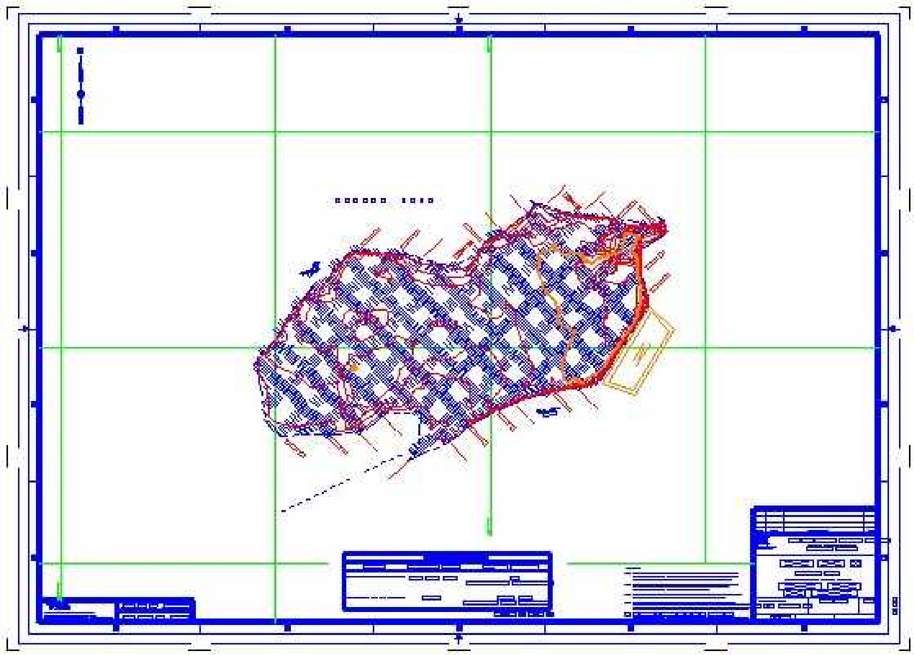

**Figure 20-2. Line spacing and alignment layout for hydrographic surveys of Almond reservoir (TVGA, Inc.)**

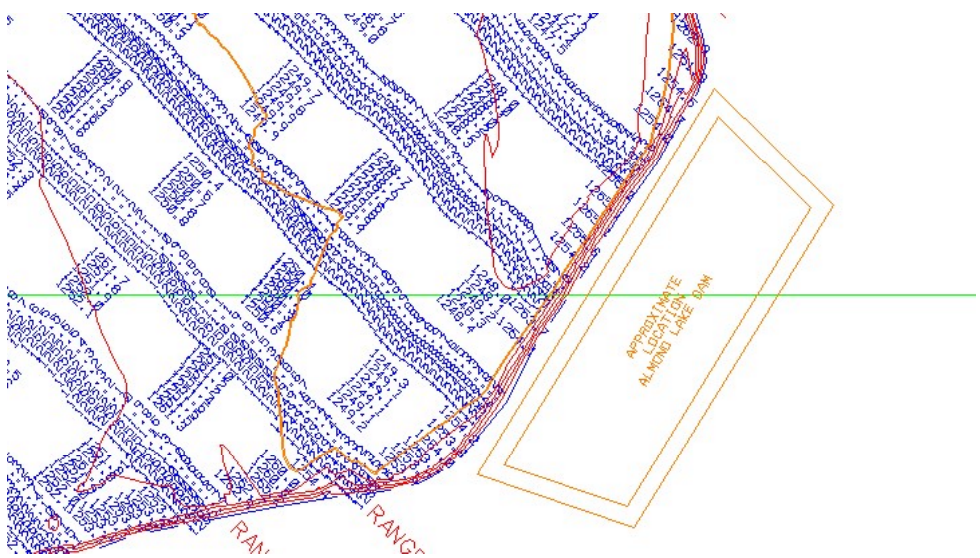


**Figure 20-3. Detail of survey vicinity Almond Lake Dam. 2-ft contours shown on drawings--
1-ft contours used to compute storage capacities (TVGA, Inc.)**

## 20-4. Area-Capacity Computations

The contractor submitted preliminary area-capacity computations between elevations 1244 and 1260 ft, using procedures described in the above report. The elevations between 1257 and 1260 ft were estimated using digitized quad maps. Once the subsequent photogrammetric DTM was delivered by Horizons, Inc., the district computed area-capacities using the full elevation range up to the top of dam at 1320 ft.

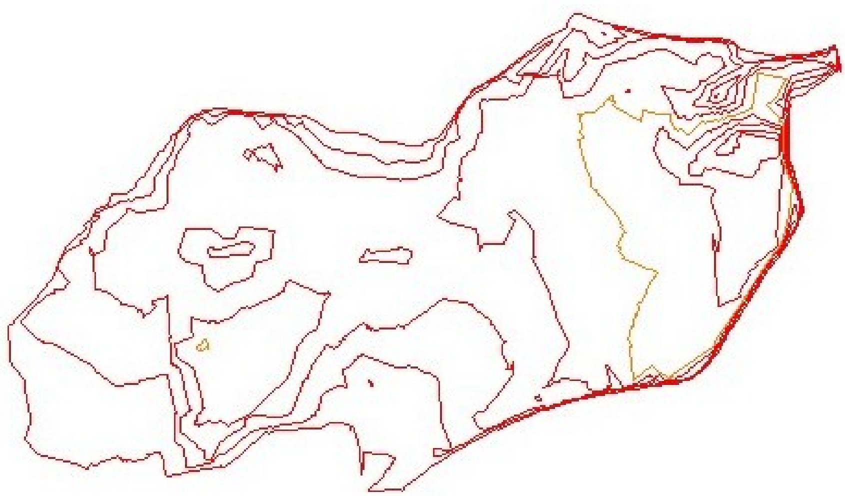

**Figure 20-4. Reservoir storage contours generated from Triangulated Irregular Network using MicroStation Inroads. Note that only 2-ft intervals are shown**

**Area/Capacity Table -- Almond Lake, New York**
Revised June 1998 by Baltimore District Water Control Management Section

| Elevation NGVD 29 (ft) | Area Acres | Capacity Acre-ft | Inches of Runoff | |
|---|---|---|---|---|
| 1229 | 0.0 | 0.0 | < 0.01 | Intake Sill elevation |
| 1230 | 0.0 | 0.0 | < 0.01 | |
| …… | | | | |
| …… | | | | |
| 1241 | 0.0 | 0.0 | < 0.01 | |
| 1242 | 0.0 | 0.0 | < 0.01 | |
| 1243 | 0.1 | 0.1 | < 0.01 | |
| 1244 | 0.2 | 0.2 | < 0.01 | |
| 1245 | 0.9 | 0.8 | < 0.01 | |
| 1246 | 1.5 | 2.0 | < 0.01 | |
| 1247 | 3.8 | 4.7 | < 0.01 | |
| 1248 | 6.0 | 9.5 | < 0.01 | |
| 1249 | 12 | 19 | 0.01 | |
| 1250 | 18 | 34 | 0.01 | |
| 1251 | 30 | 58 | 0.02 | |
| 1252 | 42 | 94 | 0.03 | |
| 1253 | 60 | 144 | 0.05 | |
| 1254 | 77 | 213 | 0.07 | |
| 1255 | 87 | 295 | 0.10 | |
| 1256 | 96 | 387 | 0.13 | Areas below elevation 1260 ft |
| 1257 | 104 | 487 | 0.16 | from hydrographic surveys |
| 1258 | 111 | 594 | 0.20 | |
| 1259 | 123 | 711 | 0.24 | |
| 1260 | 135 | 840 | 0.28 | Conservation/Recreation Pool |
| 1261 | 142 | 978 | 0.33 | |
| 1262 | 150 | 1125 | 0.38 | Areas above elevation 1260 ft |
| 1263 | 158 | 1278 | 0.43 | from aerial mapping surveys |
| . | | | | |
| . | | | | |
| 1300 | 492 | 13397 | 4.50 | Spillway elevation |
| . | | | | |
| . | | | | |
| 1306 | 540 | 16,277 | 5.47 | |

NOTES:

A. Drainage area = 55.8 sq miles
B. 1 in. of runoff = 55.8 $mi^2$ * 640 $ac/mi^2$ * 1 ft/12 in. = 2,976 acre-ft
C. Areas and capacities computed using TVGA, Inc. hydrographic project survey dated 20-21 November 1996 and Horizon, Inc. photogrammetric mapping surveys from June 1998
D. Spillway crest = 1,300 ft
E. Area/capacities for all elevations not shown

## 20-5. Area-Capacity Curves

Figure 20-5 illustrates a standard Area-Capacity curve for reservoir storage. This particular curve area-capacity curve is based on the hydrographic data obtained up to 1257 ft plus digitized quad elevations up to 1260 ft. The final area-capacity curve from the full DTM is not shown.

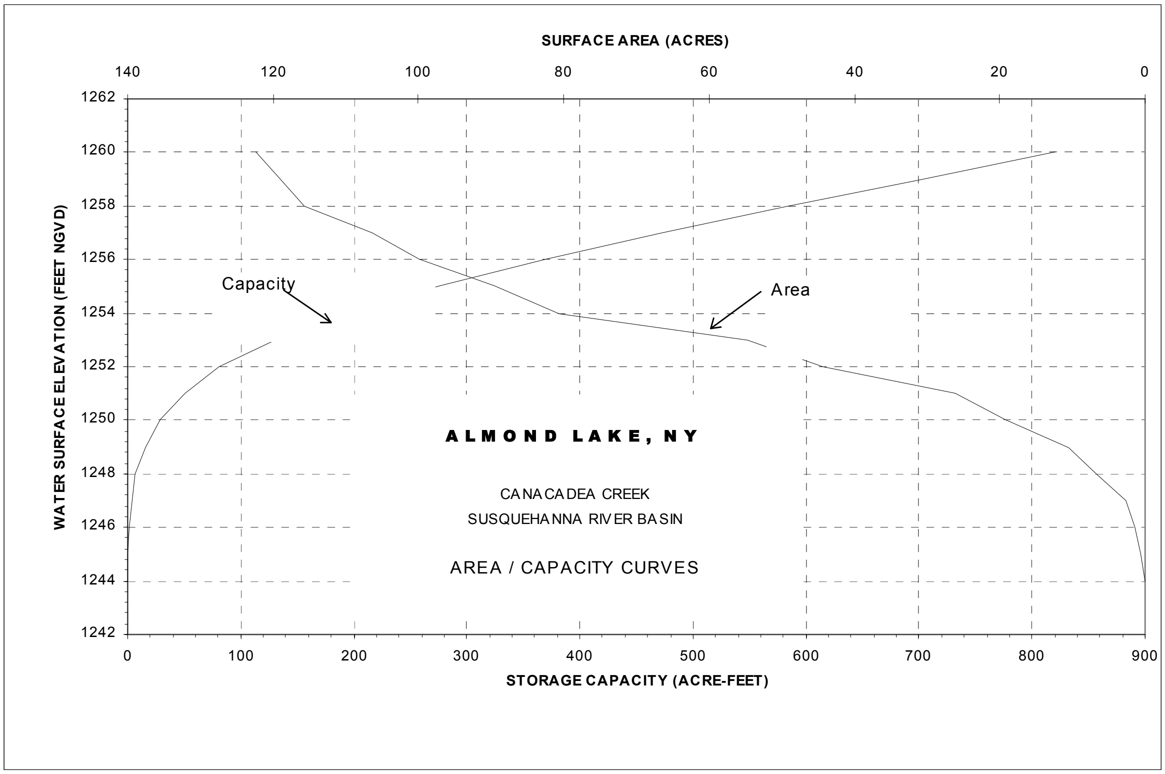


**Figure 20-5. Preliminary area-capacity curve below conservation pool at time of survey**

## 20-6. Mandatory Requirements

There are no mandatory requirements associated with this chapter.